Defense Horizons

Number 31

A publication of the
Center for Technology and National Security Policy
National Defense University

SEPTEMBER 2003

Technology, Transformation, and New Operational Concepts

by Elihu Zimet, with Robert E. Armstrong, Donald C. Daniel, and Joseph N. Mait

Overview

Throughout history, technology has been central to warfare, often giving qualitative advantages to numerically inferior forces. Typically, the rate of technology development has been relatively slow and the introduction of new weapons systems even slower, which has allowed evolutionary development of operational concepts. Today's accelerated pace of technology development no longer allows sequential development of operational concepts. In addition, the current global political environment has placed demands upon the military that range from engaging in major regional conflicts to stabilization, reconstruction and peacekeeping, all creating a continuous need for flexible, adaptive systems and new concepts of operation.

The first purpose of this paper is to describe principal new developments in technology in the framework of how they can improve operational effectiveness in the uncertain world of the 21st century. The technologies are presented generically rather than by system, because a broader and more generic technology base is required to meet evolving opportunities. A second purpose is to examine the related issue of technology development and acquisition. Expectations for the rapid introduction of technologies that promote transformation must be tempered by the military requirement for continuous capability, even as new systems and operational concepts are introduced. Finally, although the United States leads the world in the development of military systems, the foundational military science and technology base shows signs of erosion. This erosion must be arrested if American military superiority is to be maintained.

The Role of Technology in Transformation

The military that was developed to fight the Cold War in a bipolar world must transform to meet current and future challenges. Retired Vice Admiral Arthur Cebrowski, head of the Office of Force Transformation, has discussed transformation in the context of three new strategic elements: globalization of information, ideologies, and economic opportunities; transition from the familiar Cold War threat to one that is non-nodal, more pervasive, and often nonstate, nondeterable, and nondetectable; and reduced cost of information technology, which has lowered the barriers to competition and tended to level the technology playing field—that is, technology alone will be insufficient to ensure American military superiority. More important is how technology shapes and is employed by the military—how it promotes transformation. Transformation is important because the resources of the U.S. military, while the greatest in the world, are still limited both in materiel and personnel. Limits mean choices, and in the turbulent global environment, choices mean changes.

Developers of technology are inclined to claim that their products are "transformational." However, even such emerging technologies as information systems, hypersonic weapons, and unmanned vehicles are not intrinsically transformational. Their military relevance must be demonstrated in the context of their contribution to the creation of a truly joint force that can create decisive military effects in support of a global strategy to defend and promote American national interests globally.

Technology can be *evolutionary*, that is, contribute systems that fit within existing operational concepts and organization, or *revolutionary* or *disruptive*, that is, require new operational and organizational structures to realize an enhanced military capability. In general, technologies that are disruptive promote broad transformation by requiring military organizations to adapt to radically new capabilities.

Typically 15 to 20 years pass while a weapons system moves from concept development through engineering development, prototyping, manufacturing, and operational evaluation to initial operational capability. Therefore, to anticipate the impact of new technologies on transformation in the next decade, it is not necessary to predict the future of new technology, but rather to look at currently emerging technologies, such as the unmanned combat aerial vehicle (UCAV) and the airborne laser boost-phase missile defense system, and relate them to the emerging military tasks or missions expected of the armed forces in the future, as well as to the military attributes assigned to a transformational force.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2003**	2. REPORT TYPE **N/A**	3. DATES COVERED **-**

4. TITLE AND SUBTITLE **Technology, Transformation, and New Operational Concepts**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **National Defense University Center for Technology and National Security Policy Fort McNair Washington, DC 20319**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release, distribution unlimited

13. SUPPLEMENTARY NOTES
The original document contains color images.

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**UU**	**8**	

Transformation Defined

The Department of Defense (DOD) Transformation Planning Guidance of April 2003 defines transformation as

> a process that shapes the changing nature of military competition and cooperation through new combinations of concepts, capabilities, people and organizations that exploit our nation's advantages and protect against our asymmetric vulnerabilities to sustain our strategic position, which helps underpin peace and stability in the world.

The process of transformation entails new technologies (warfighting systems), new operational concepts (network-centric warfare, effects-based operations, rapid reaction forces), and new organizational structures (homeland defense, special forces, joint operations). The broad aim of transformation is to develop joint, network-centric, distributed forces capable of rapid decision superiority and massed effects across the battlefield.

The Quadrennial Defense Review (QDR) provides a framework for transformation and sets requirements for protection of the homeland, including information network attack, assured access to distant theaters, joint operations, space, and protection of space assets. A wide variety of technologies are required to satisfy QDR objectives. Requirements include nuclear, biological, and chemical protection, ballistic and cruise missile defense, mine detection and neutralization, hard and buried target destruction, operations in urban environments, and global real-time threat surveillance. In addition to the QDR, the Conventional Forces Study, Final Report (the Gompert Study, spring 2001) highlights 12 "military tasks" that provide a framework to lay technologies against. These 12 military tasks are air combat; missile defense; naval strike; ground combat; long-range strike; air strike; amphibious combat; space operations; information war; command and control; sensors and reconnaissance; and strategic mobility.

Several recent transformation guidance and roadmap documents published by DOD present attributes or goals of transformation:

- Transformed forces need to be flexible, versatile, adaptable, and agile in order to handle a spectrum of future missions, crises, enemies, and wars. Forces, therefore, need to be modular and scalable.
- Future operations will be highly joint, with agile ground forces supported by precision strikes from air forces supported directly from the sea and from the continental United States.
- Transformation requires the ability to acquire information and imagery; process information; make decisions; and distribute information over broad areas, at high data rates, on the move, and across all echelons. These capabilities are the enablers of network-centric warfare. DOD refers to systems that support these capabilities as C4ISR (command, control, communications, computers, intelligence, surveillance, and reconnaissance).
- Fast-moving, rapidly deployed forces to distant areas require agile logistical support and transportation.
- System and capability costs must be treated as independent variables. Transformation must be affordable.

Technologies for Transformation

The impact of technology on these attributes or goals is examined below in five broad areas: information, materials, power and energy, human performance, and biology. A sixth area, derivative system technologies, describes system level developments that also are significant to transformation.

Currently, the DOD science and technology base is compartmented into many sub-areas that include technologies, systems, and platforms. This makes it difficult for DOD to set funding priorities and to explain and defend the program. As DOD looks to revitalize its science and technology base, this broad classification of technologies could help focus efforts on emerging opportunities and guide oversight of the services.

Information Technologies

Superior information always has been a discriminator in the success of military operations. However, the speed with which information can be distributed and processed, and the quantity of information and data that can be transmitted and received, have transformed military operations. The advantage the U.S. military enjoys over the rest of the world probably has more to do with information superiority than with platforms and weapons. Information technology, applied to the operational concept of netted warfare, has been demonstrated convincingly in the ground and air teaming of ground-based target designators and air-delivered ordnance. Netting ties together distributed sensors, weapons, and decisionmakers. As noted in the discussion of functional materials, order-of-magnitude improvements in processing speeds through successive generations of chip development based on optical lithography manufacturing will eventually reach physical limits because of quantum effects and practical limits due to, for example, the cost of chip foundries. This not only will open the door to other paradigms of chip development but also will stress development of new computing architectures and, in particular, software development.

Information technologies are tremendous force multipliers to operations; however, they also introduce vulnerabilities in proportion to dependence on them. In addition, information technology is disseminated rapidly and is already being used as a cohesive tool for international terrorism. During the next decade, a major focus for the military will be in networking mobile distributed systems from sensors to combat operation centers and decisionmakers to weapons platforms and to the dismounted soldier or marine. Specific technologies to achieve this networking are as follows.

Self-forming/healing, mobile, wireless, reconfigurable, secure networks. The backbone of network-centric warfare is the connectivity among sensors, weapons, and decisionmakers. In order to distribute information at high data rates across broad areas while on the move, either networks without a fixed infrastructure or untethered networks are required. Current receivers and transmitters, while

Elihu Zimet is a Distinguished Research Professor at CTNSP. He may be contacted at zimete@ndu.edu or (202) 685–3586. Other CTNSP staff who contributed to this article are Donald C. Daniel, a Distinguished Research Professor, and Robert E. Armstrong and Joseph N. Mait, Senior Research Fellows.

mobile, require a fixed infrastructure of repeater towers, servers, routers, and network devices. In an untethered network, all devices are mobile, including routers and servers. The network must be capable of self-organizing in an ad hoc but energy-aware fashion. The establishment and maintenance of the network should be transparent to the users. Connectivity must be available in all environments, including urban and under canopy, where line of sight is limited.

Distributed netted mobile and embedded sensors. Sensors are the information collectors that, when coupled through a network, lead to a real-time, tactical level of situational understanding by providing imagery, identity, location, and status. The sensors can be located on a wide array of platforms, hence, can be mobile or embedded in equipment, containers, or even people and other organisms. The future battlespace will include urban and guerilla warfare. Distributed sensors are essential to these environments in which a line of sight from an overhead collector is often lacking. The impact of netted sensors is already evident on the battlefield. Current systems for precision strike include space-based sensors and sensors on high altitude platforms, such as Global Hawk, on tactical aircraft, both manned aircraft and unmanned aerial vehicles (UAVs), and ground-based observers. Systems to net sensors for air defense include the Navy Cooperative Engagement Capability.

Considerable success has been demonstrated in the rapid precision targeting of fixed and moving targets in open terrain, but not yet in targeting through foliage, in an urban environment, or where discrimination of target from background is difficult (such as in camouflage or while detecting mines). Challenges remain in sensor development, distribution, coverage to operate in all environments, and sensor networking. Detection and targeting from advanced sensors will be enhanced by fusing sensors that complement detection (for example, acoustic sensors can be used to cue imaging sensors for ground targets). In terms of sensor distribution, the maneuver and ground level of coverage are currently underpopulated. Mini UAVs, unattended ground sensors, robotic ground vehicles, and sensors embedded in ground-based equipment will expand coverage greatly. Finally, the issue of establishing an untethered network of sensors is essential. Future shipboard and airframe design also requires technology to integrate radar, electronic warfare, and communications functions into a single system. This will be a fundamental step toward developing interoperability within and among platforms, as well as among forces and nations.

Distributed collaborative tools for decisionmaking. Network-centric warfare provides a clear example of the development of new technology (information networks) that necessitates changes in organizational structure (hierarchical command, single-service planning, and command and control). Rather than being hierarchical, network-centric warfare assumes a flattened command structure with a rapid decision cycle. The objective is to move information rapidly out to the edge of the network (that is, to the tactical-level end-user). Network-centric warfare enables the integration of air and ground forces with artillery for close-air support, as seen in Iraq. Paradoxically, while network technology enables information to move rapidly outward (thereby promoting distributed decisions), it also allows for interactive decisionmaking throughout the network (thereby encouraging micromanagement). Achieving high-speed decision making and the command and control of dispersed joint forces, including unmanned systems, is both an operational and a technological challenge. Decision aids, machine intelligence, and collaborative tools can enable rapid decision making at the right command levels; the rest is up to humans.

Information assurance, integrity, and reliability. If network-centric warfare is to be a dominant military operational concept, its vulnerabilities must be addressed. To date, no military opponent has mounted a serious attack on our information connectivity or computer infrastructure, but vulnerabilities are known to exist, and a future adversary will adapt tactics and systems to attack them. For example, the success of the joint direct attack munition is based on its global positioning system (GPS) guidance, which has a known susceptibility to jamming. Additionally, the increased military use of commercial off-the-shelf (COTS) information technology products creates vulnerability, because they are not hardened against attack and because their general availability enables enemies to acquire similar capabilities and to become familiar with their vulnerabilities. Techniques to increase the integrity and reliability of our netted systems include redundant data links, self-healing networks, hardening of components, and low-probability-of-intercept communications. As in electronic warfare, countermeasures and counter-countermeasures will unfold over time. New software and hardware are required to combat network attack and to ensure the uninterrupted flow of accurate information.

Sensing and predicting the environmental battlespace. The ability to perform surveillance, targeting, networking, and force deployment and to predict chemical and biological agent dispersion is predicated on knowledge of the operational environments, including the oceans, atmosphere, and space. Both natural environmental events and manmade obscurants must be considered. Sensing and predicting tools are needed for "now-time" weather/environment casting and for weapon/sensor optimization and protection of assets.

Material Technologies

While new materials are not usually considered transformational, they are the building blocks of every device or system that is pro-transformational. There are two basic classes of material, functional and structural. *Functional materials* are primarily the materials used in electronic devices, such as transistors, detectors, emitters, fiber optics, and displays. "Memory" materials, which return to their original shape when subjected to temperature changes, also are functional materials, as are superconducting materials. The important properties of *structural materials* are strength, density, corrosion resistance, thermal conductivity, and other mechanical properties. As the ability to manipulate material structure to nanoscale levels (nanotechnology) matures, new materials with selectable properties will emerge in both classes. Current and future materials have important implications for transformation, as does the ability to manufacture them affordably.

Functional materials. More bandwidth, greater processing speeds, smaller sensors and detectors, higher-power transmitters, and all the other elements of network-centric warfare are in increasing demand The information age is a direct result of continued

progress in new semiconductors and, in particular, the ability to package more integrated circuits onto chips. this technology is the backbone not only for information processing but for advanced sensors, transmitters, solid-state lasers, and displays. Nanoscale technology will drive miniaturization even further, although the pace of miniaturization described by Moore's Law cannot be sustained indefinitely under current industry paradigms.

Another technology that has matured to developmental utility is that of wide band-gap semiconductors. These materials will play a major role in transmitters and receivers for broadband communications, radar, and electronic warfare.

Looking further into the future, computer systems that rely on biological molecules to store information are under development. Proteins have unique folding patterns that provide an opportunity to store data in three dimensions, ultimately creating a several-hundred-fold capacity advantage over standard optical storage.

Superconducting materials, which have been available for several decades, have opened up many new areas of science (for example, magnetic resonance imaging and particle accelerators). However, their practical use has been limited by the need to operate at the temperatures of liquid helium (4 K [Kelvin]) or, at best, liquid nitrogen (77 K). In the late 1980s, important discoveries of superconductors capable of operating at much higher temperatures (over 130 K) were made. However, in the intervening years the weak mechanical properties and other problems have prevented these materials from being used in practical devices. A high-temperature, superconducting power line or motor would have an enormous effect on power transmission and mobility of all-electric vehicles, including ground vehicles, ships, and submarines, but such advances depend on more scientific understanding and breakthroughs.

Structural materials. The current vision of transformation stresses global rapid response, mobility, and survivability. The Army and Marine Corps require air-transportable surface vehicles light enough to be transported, yet tough enough for combat. The requirement for a lighter, more agile, and more lethal force drives the search for new materials that are lighter, stronger, survivable at higher temperatures, and resistant to corrosion.

Weight and strength, as well as signature, are paramount for aircraft materials and have sparked the evolution of composite aircraft including UAVs for the Air Force and Navy as well as helicopters for the Army and Marine Corps. Weight and strength also are major factors in ship design. The Littoral Combat Ship envisioned by the Navy, a high-speed vessel with good stability at high sea-states and a high payload fraction, will depend on new structural materials to demonstrate its potential for warfighting.

The ability to manipulate molecules down to the atomic scale already has impacted material design. Fabrication techniques borrowed from solid-state electronics have led to the use of microelectromechanical devices that can reduce the size and cost of munitions. Continuing advances in lightweight body armor for personnel protection could incorporate health monitoring and cooling. Significant progress has been made in composite materials, particularly in their manufacture in large integral shapes and also in methods of fault testing and repair. The advances in the understanding of the basic properties of materials, coupled with advances in computer science, make it possible to design new materials to achieve the macro properties desired without long-term testing, which, in turn, reduces the development costs of new structural materials.

Energy and Propulsion Technologies

Transformational concepts of rapid deployment, dispersed forces, and high mobility imply creation of highly energy-dependent forces that do not rely on establishing fixed bases of energy resupply. With the possible exception of nuclear carriers and submarines, military systems, including humans, are limited by the amount of energy they can carry. Two strategies exist to address this problem: develop materials with higher energy density and improve the efficiency of energy use. Advances have been slow but continuous in both of areas

Compact, lightweight, long-lasting energy sources. Significant gains in battery technology and fuel cell technology have been made over the last few decades, although the development of efficient systems that run on alternative fuels instead of petroleum products is still in its infancy. While military operations currently are not restricted by cost or availability of petroleum products, this could change suddenly, especially in a crisis.

The dismounted soldier and marine will carry increasing amounts of electronic equipment. The logistics problems of supplying fuel and batteries to a mobile, dispersed force could make energy distribution a limiting factor in future operational concepts, such as the Army's Future Combat System. High-density energy sources are required together with a reduction in the power demands of new equipment. Information systems increasingly have become significant users of energy on the battlefield. Mini UAVs and small munitions require advances in compact energy sources to be able to accomplish their projected mission profiles. Fortunately for the military, energy storage technology has a considerable commercial market that has driven substantial investment.

Advanced propulsion for aircraft, missiles, and access to space. The greatly decreased time in detection, decisionmaking, and targeting brought about by information technology and networking, and the increased standoff distances from targets (necessitated by air defenses and enabled by GPS guidance) have increased the importance of aircraft or missile time of flight in the time window from detection to kill.

Currently, both attack aircraft and air-breathing cruise missiles designed for long ranges (hundreds of miles) are powered by turbine engines and have maximum speeds in the subsonic or low supersonic range. In order to hit time-critical, hardened, or deeply buried targets at long range within minutes and take advantage of the reduced decision cycle time of network-centric warfare, missile velocities need to increase to Mach 6 or better (the demarcation between supersonic and hypersonic speeds is about Mach 5, or five times the speed of sound). The air-breathing engine technology under investigation to achieve these speeds is ramjet propulsion, in which the fuel is burned at supersonic speeds (this concept is known as a supersonic combustion ramjet, or SCRAMJET). Hypersonic propulsion also is being investigated for both aircraft and missiles. For missiles, in addition to the benefit of reduced time of flight, high speed increases kinetic energy deposited on the target, which can exceed the energy of an explosive warhead. This could lead to an effective

weapon against buried and hardened targets. For aircraft, an additional application of the technology is affordable access to space, first in two stages and ultimately in a single stage to orbit. Space basing of intelligence, surveillance, and communication systems is essential for network-centric warfare, yet current space lift is limited and expensive.

Substantial gains have been made in propulsion technologies. Turbine engine technology has increased the ratio of thrust to weight through high temperature materials technology, computational fluid mechanics, and computer-aided design and manufacturing. Propulsion demands for time-critical strike, high-altitude operations, mini UAVs, and affordable space access have provided requirements for new propulsion systems. Current technology programs are addressing these requirements.

Human Performance Technologies

Transformation of the military incorporates technology, operational concepts, and organization. As the connecting link among these, humans need new skills and abilities. Technological change requires continuous training despite the decreasing availability of test ranges and training flight hours. In addition, long deployments can increase the intervals between conventional training in military bases and schools. Technology offers opportunities to improve both training and human performance.

Immersive virtual training and distributed learning. Developments in information technology already have made a significant impact on training. With considerable assistance from the electronic game and entertainment industry, coupled with virtual reality environmental trainers, training systems correspond with actual combat to an unprecedented degree. Training software now is embedded in actual equipment, allowing continuous training on station. In addition, warfare itself has moved from the mostly physical to the mostly mental demands of information management and decisionmaking; thus, virtual training particularly approaches operational conditions in information age warfare. Of course, new immersive and embedded trainers also have enhanced rifle training, tank driving, and pilot training.

Advances in virtual reality trainers with full sensory cues coupled with realistic interactive simulation will provide training in realistic scenarios. Advances in information technologies have created a revolution in teaching and training methods. These teaching advances, in turn, will continue to lead to a transformation in the training of military personnel. These techniques may be equally valuable in enhancing classroom learning, distance learning, and learning among groups of students in dispersed locations.

Enhanced human performance. In addition to training, direct means of improving human performance are under investigation, including mental and physical enhancements. Studies on the effects of stress on decision making and on how to cope with fatigue and sleep deprivation will lead to enhanced performance. Investigations of human physiology and biology can lead to improvements in warfighter capabilities degraded through stress and environment. These include countering sleep deprivation through control of neurotransmitters; identifying genes that predispose troops to superior environmental adaptation, physical performance, or both; and enhancing mission preparation by stimulating nerve development for short-term memory. These studies must include potential long-term effects on the individual.

Biotechnologies

Historically, the military has associated biotechnology with infectious diseases, the treatment of wounds, or biological warfare. Recently, and independent of the military, a major biotechnology industry has developed with an almost unlimited potential for new military applications. Biotechnology probably will succeed information technology as the next technological surge, and the military implications—and the ethical, legal, and regulatory issues—remain to be addressed.[5] Biological analogues to the other technology areas described above are currently in development. They include sensors, information processing and storage, specialized materials, sources of electrical and chemical energy, and human performance enhancement. In addition, nature has provided algorithms for complex behavior such as navigation that can be mimicked in conventional electronic circuits.

Advanced military medicine and protection. In the near term, medicine and protection will remain the principal application of biotechnology to military uses. The mobility and dispersion of forces in a transformed military imply the need for more on-the-spot medical stabilization and treatment when evacuation is delayed or unavailable. An example of both treatment and prevention is accelerated wound healing using light-emitting diodes (LEDs). Preliminary research has shown that near-infrared LED treatment can accelerate human wound healing by up to 50 percent. Also, biomaterials can be developed to control excessive bleeding, which accounts for over half of battlefield deaths. Biomonitors that could be incorporated in body armor would provide both individual and commander a continuous medical status report. Edible vaccines genetically engineered into food could deliver immunization quickly to a large group.

Nonmedical biotechnologies. Biology can provide a broad range of materials and sensors for the battlefield that can augment conventional systems or, in some cases, provide unique capabilities. For example, a bacterium, *bacteriorhodopsin*, absorbs microwave radiation in the X band and higher frequencies. Plant proteins could be the basis for infrared signature reduction in paints. Biological systems can provide structural patterns that diffract light (as do bird feathers). These biological materials can yield advanced camouflage and stealth characteristics to a number of systems. *Bacteriorhodopsin* also has been shown to have the potential for electro-optical memory devices with high storage capability in very small volumes that can withstand environmental abuse. Biosensors are biological devices that can detect, capture, concentrate, and analyze specific molecules or life forms. A small, wearable device could be used to warn of chemical or biological attack. Biological materials also can provide weight and volume advantages over conventional materials. Finally, biomass (the leaves and stalks of agricultural crops) represents a source of ethanol for fuel that could be processed in theater, thereby reducing the logistics problems of fuel transport.

Biomimetic technologies. Over time, nature has evolved strategies and biological processes that can be emulated in electromechanical systems. These bio-inspired systems do not necessarily

make use of biological materials. Growing evidence suggests that neural circuits and strategies evolved by insects over millions of years will prove to be fruitful sources of new approaches to navigation, target recognition, clutter rejection, target tracking, hyperacuity, efficient circuit design, and other characteristics desired for advanced imaging weapons. Understanding the biosonar and bioradar in animals will lead to the design of more capable sonar and radar systems for military applications. In addition, the underlying neurology of swarming insects could provide a basis for the operation of multiple mini UAVs.

Derivative System Technologies

Inventions with the impact of the transistor, superconducting materials, and the nuclear reactor are rare; most new systems evolve from interdisciplinary synergies. The Predator UAV, for example, is as much a product of advances in sensors, information processing, advanced data links, GPS and inertial guidance, advanced materials, and lightweight, highly efficient propulsion as it is of aircraft aerodynamics and structures. Stealth aircraft are a marriage of aerodynamics, computer flight control, structural radar absorbing materials, and electromagnetic technologies. The current preeminence of long-range, time-critical precision strike has evolved from advances in automation, information, advanced sensors and surveillance systems, and precision munitions; further technological advances will extend our capability to destroy moving, buried, and hidden targets and will reduce collateral damage and fratricide. As the emerging field of biotechnology develops and couples with information technology, new components and systems will evolve.

Automated systems, robotics, unmanned vehicles. Automation has evolved from the marriage of computers and microprocessors with advanced sensors and mechanical systems. While largely transparent to the user, devices from home thermostats to automobiles contain a degree of automation that users have come to expect and trust. In highly complex control systems, such as the flight control of a military jet aircraft, the pilot provides the command/decision function through the joystick, but a computer controls the actuators that fly the plane. In fact, the plane will be unstable without the dynamic control of the computer. With information flowing to the pilot from on-board sensors and displays (rather than exterior visual sightings) and with control of the vehicle managed through a computer, it is a logical step to connect the pilot to the vehicle through a wireless data link resulting in an unmanned vehicle.

The next step in this development is to increase the degree of decisionmaking or autonomy in the platform while retaining command control in the loop. For example, the Predator UAV is remotely piloted, while the Global Hawk is given only waypoints. Beyond this, the UCAV under development will have considerable autonomy in flight and target acquisition. Similar progress is being made in ground, sea, and underwater vehicles. Automated systems will become increasingly important as tools in such hostile environments as urban and guerrilla warfare, and technology will lead to more autonomous, netted systems coupled with manned systems incorporating both sensors and weapons.

Spaced-based systems. Operational concepts such as network-centric warfare and effects-based operations require space-based assets for global communications and surveillance. While space is an environment rather than a technology, unique technology is required to operate there. These technologies fall under the categories of automation, unique sensors, unique propulsion, special materials, and survivability against vacuum, radiation, cold, microparticles, and such man-made threats as jamming. Small, inexpensive microsatellites hold the potential for greatly reducing the cost of military satellites without loss of capability. They promise rapid launch and lower cost to orbit. Clusters of such satellites offer the potential for less vulnerability and greater precision of associated systems. As automation technology matures, unmanned vehicles will be developed for repair of satellites in orbit.

Integrated electric vehicles, C4ISR, and weapons. With continued advances in electric power generation and storage, electric motors, high-power radars and communications, electronic warfare, and directed energy weapons, the efficiencies inherent in developing integrated electrical systems for vehicles incorporating electric propulsion, surveillance, and weaponry could have a significant effect on combat effectiveness. While superconducting motors for propulsion remain in the technology base, significant advances in efficiency and size reduction have been made in permanent magnet motors. These advances make the use of electrical power for ships and land vehicles competitive with conventional diesel and gas turbine propulsion. Electric propulsion also reduces the noise and other signatures of the vehicles as well as increasing their mission flexibility. The electric demands for radar, communication, and electronic warfare have increased significantly due to increased demands for detection and tracking of low observable targets and such new missions as ballistic missile defense for ships.

Directed energy weapons, powered by electricity, may have unique attributes to address future threats. These include near-instantaneous transmission times, surgical precision for limited collateral damage, and power scaling for potential use as nonlethal weapons. In addition, slow but steady progress has been made on electromagnetic guns (also referred to as rail guns). These guns have the potential for extremely high projectile velocities that translate to long range and high lethality with a hit-to-kill (no explosive warhead) capability. Total system efficiency for an all-electric vehicle also would benefit from the use of a single fuel to run the electric generator. This would significantly reduce the current logistics and safety problems of providing multiple energetic fuels, propellants, and warheads to a combat ship or ground vehicle.

Precision munitions. Precision munitions have already demonstrated their utility in Afghanistan and Iraq. Further advances will come in better integration between weapons and future platforms, such as UCAVs, more survivability against countermeasures, and reduced cost. Somewhat counterintuitively, few requirements exist for more precision (because of current accuracy), but with the introduction of smaller weapons, hit-to-kill warheads, and demands to reduce collateral damage, this requirement will reappear. Small smart bomb technology enables internal carriage of large numbers of independently targeted, autonomous weapons, while not degrading the low-observable characteristics of the future manned and unmanned attack aircraft that will carry them. They are essential for

the future success of platforms such as Joint Strike Fighter, F–22, and UCAV. Hard target, smart munitions technology provides the warfighter the means to hold many of the enemy's hardened and/or deeply buried structures at risk using conventional munitions. Finally, the cost of many conventional weapons can be reduced by over an order of magnitude by using COTS components, including guidance, propulsion, sensors, and data links that in many cases are available on the Internet. The technology to integrate these components into weapons systems with significant military potential is in hand. These affordable weapons systems could be effective against many targets, conserving the inventory of high-performance, high-cost weapons systems for hardened and protected targets.

Improving Technology Acquisition

A major hurdle in the introduction of new technologies is difficulty in making the transition from the laboratory to system acquisition. The technology base does not always produce options that improve on the military utility of existing operational systems so there is resistance in a service to taking the risk of a new start. Yet, once started, programs develop a life of their own and are very hard to stop. New system acquisition, or modernization, is expensive; once underway, alternatives tend to be foreclosed for reasons that relate both to resources and to service and bureaucratic interests.

A complex, bureaucratic acquisition process has evolved with the principal objective of providing multiple decision points to eliminate costly, bad decisions, not to encourage innovation. The objective of acquisition reform, then, is to simplify and accelerate the process and to foster innovation consistent with transformation without inordinately increasing risk. While this is a tough challenge, it is not impossible; already, several steps have been taken in the right direction. DOD has rewritten the 5000 series acquisition directive and instructions to speed up and simplify the process. This could allow more flexibility in contracting, though the jury is still out. Also, on April 10, 2003, DOD submitted to Congress proposed legislation for "Defense Transformation for the 21st Century," including acquisition transformation.

Another obstacle to the implementation of new technology is the so-called "funding valley-of-death," created by not programming development funds until the technology has been demonstrated successfully. The DOD Planning, Programming, and Budgeting System (PPBS) cycle begins more than 2 years before a development program is initiated. Thus, a significant delay—and, most importantly, loss of continuity—is built into the transition of a technology from advanced development to engineering development.

A logical approach to eliminating this technology development gap is to preposition future funding in the engineering development account based on metrics for transition established by a memorandum of agreement. The Navy has adopted this approach in its Future Naval Capabilities (FNC) initiative. While this approach accelerates transition, it makes sense for only a portion of the advanced development account. This process works for incremental, evolutionary concepts but tends to eliminate technology risk taking. No ready home is provided for disruptive technology that may emerge and require a new program office.

Another way to shorten the transition period of a new technology is spiral development, which allows the fielding of a new system well short of full potential capability. Through a spiraling series of upgrades, capability is added in subsequent stages. This process allows operators to provide input as the system evolves. To be successful, a spiral development program must navigate between having enough initial capability to demonstrate military utility according to current standards and over specification of requirements by operators, which can result in unacceptable risk and cost.

Still another way to shorten the acquisition cycle time is to require a degree of concurrency between the sequential stages of technology development, technology demonstration, system demonstration, acquisition, operational doctrine development, and training. An approach to this concurrency is the use of demonstrations and operational experiments that involve both developer and user.

Ultimately, the adoption of new technologies employed in new operational concepts will be paced by budgetary tradeoffs with existing systems and other service funding requirements, such as readiness and maintenance. Also, as the United States works toward jointness and interoperability across service platforms and systems, changes to the current separate service acquisition system will be required to build jointness into the requirements process. A long-term view of transformation indicates that, in addition to technologies, operational concepts, and organization, a new look at acquisition and the PPBS process is required. In this regard, DOD released on May 22, 2003, a streamlined PPBS process called the Planning, Programming, Budgeting, and Execution process that will evolve from a 1-year to a 2-year budget cycle and will use the alternate year to focus on fiscal execution and program performance.

Counter Currents, Concerns, Consequences

The development of military technology is a complicated dynamic carried out on an international scale. The performer base resides in universities, government-owned or -sponsored laboratories, and the private sector. Several significant trends have impacted where and how technology for the military is developed in the United States over the past few decades. Many of these trends are ominous for the future development of innovative concepts within America.

In the universities, the number of physical science and engineering degrees granted to U.S. nationals has decreased in the past 20 years. While many foreign nationals educated in the United States stay here and contribute to our research base, an increasing amount of research and engineering talent has migrated abroad. Another trend in the universities is the movement from pure research to applied research. This is done to gain industrial partnerships and expand the funding base. Yet, pure research performed in universities is the source of future technology. The decline of pure research inevitably will reduce American technological superiority.

Military laboratories have been downsized over several decades. The labs typically have played a key role in translating research advances achieved at universities and other institutions by recognizing their military applications and translating them into military capabilities. Also, scientists and engineers in the labs have

been the core developers of technologies of little commercial interest, such as high-power radar, stealth, and reactive armor. Reduced lab capabilities will result in reduced military capabilities.

With the end of the Cold War, the military-industrial base began to shrink and restructure. Largely through consolidation, the number of prime military contractors has been reduced to about five, limiting the competitive base that drives innovation and risk taking.

In addition, the services, pressed with ever-increasing operational and infrastructure costs, have tended to raid the science and technology accounts for money to preserve other functions.

On the other hand, as the military science and technology infrastructure has declined, the commercial technology base, particularly in information and communications, has grown to dwarf that of DOD. While this provides DOD with significant advances, the commercial market does not address many DOD requirements. For better or worse, DOD will have a decreasing role in setting technology requirements and will increasingly adapt its requirements to the commercial standards set in the marketplace. The success of the technological aspects of transformation will depend largely on DOD ability to negotiate the transition from the Cold War business model to an information age business model—a process that is just beginning.

Finally, the consequences of technology beyond enhanced military capability must also be considered as a aspect of transformation. For example, weapons system development has incorporated more standoff, precision, and automation, resulting in more lethality and fewer American casualties. The fact that very few Americans were killed in action in Iraq 2003 is a tribute to the effectiveness of the U.S. military and its high-tech weapons. While this outcome is desired for war, it raises ethical concerns that the antiseptic, low-risk nature of American military power may cause more frequent resort to war as a foreign policy option. Another ethical challenge lies in information technology and the increasing ability to mine vast amounts of personal data and make correlations on behavior in the search for potential terrorists. This has raised concerns about the civil liberties and rights to privacy of U.S. citizens. Yet another example is the debate raised by the use of embryonic stem cells for medical research, which highlights concerns over biotechnology development. Beyond ethical concerns in this field are fears of unknown consequences in the biological manipulation of plants and animals. Development of new technology and operational concepts cannot be done in the absence of considering their effects on the battlefield, on policy, and on society.

Summary

The U.S. military is unchallenged in its size and strength around the world today, but it still must transform to meet the threats of an evolving sociopolitical world in which conventional methods of detection, deterrence, and military action may fail. A transformed military is one that is surgical, flexible, agile, and rapidly deployable, while able to respond to attack in minutes rather than hours or days. These capabilities are the goals of new operational concepts, such as network-centric warfare and effects-based operations, that are enabled by advanced technologies. Therefore, to be transformational, a technology must be defined in terms of its operational utility to meet current and future needs. Technologies that lead to new operational concepts and organizational change are both revolutionary and disruptive. Introducing new technology to the military is a multistep process from invention through engineering development, testing, acquisition, and training. While reducing the time from invention to deployment is achievable, it remains fundamentally a multiyear process. The technology employed to such good effect in Afghanistan and Iraq was essentially developed well over a decade ago (in some cases three decades ago), while technology developed in the 1990s has not yet been deployed.

This paper has examined several of the emerging technologies under a broad taxonomy with the intent of showing their application to a transformed force employing new operational concepts. The taxonomy was chosen to be technology-generic rather than systems-oriented due to the uncertainty of system requirements for the future, and it might serve as a basis for DOD oversight and exposition of the technology base. Biotechnologies are emerging as an area with potential for new medicines, materials, sensors, and energy, as well as for biological threats. However, it is not an area that DOD has much impact in or knowledge of, and the commercial technology base is focused mostly on medicine.

Technology superiority has been a fundamental pillar of the U.S. military since World War II, and our national leaders tacitly assume that this superiority is sustainable. This assumption needs to be challenged. In recent years, the military has increasingly relied on science and technology funded by other agencies and developed in the private sector. Within the private sector, technology—in particular information technology—has migrated globally. By the usual metrics of measuring science and technology, such as advanced science and engineering degrees granted, papers published, and patents granted, the United States is still the world leader, but trends are in the other direction, as countries such as China build a powerful technology base. Both in the near and long term, the migration of technology is an area well worth watching.

Defense Horizons *is published by the Center for Technology and National Security Policy through the Publication Directorate of the Institute for National Strategic Studies, National Defense University.* **Defense Horizons** *and other National Defense University publications are available online at http://www.ndu.edu/inss/press/nduphp.html.*

Center for Technology and National Security Policy

Hans Binnendijk
Director